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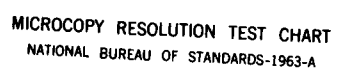UNCLASSIFIED   D A MILBURN ET AL. 1983   F/G 8/3   NL

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STATIC AND DYNAMIC ANALYSIS OF A DEEP-WATER SUBSURFACE MOORING FOR NEAR-SURFACE CURRENT MEASUREMENTS

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Abstract

The performance of a single-point subsurface mooring for near-surface curre
measurements in the Gulf of Mexico is examined. Using state-of-the-art computer
programs for static and dynamic analysis of single-point moorings, the response
a proposed design to forcing caused by ocean currents, waves, and deployment is
predicted. These predictions are, in turn, compared with the performance criter
specified to evaluate the proposed design. It is found that the proposed design
is reasonably rigid and, with high probability, will survive the environmental co
ditions assumed. Selected computer solutions are shown and discussed.

Introduction

The Naval Ocean Research and Development Activity is planning an oceanograp
experiment to gather data on the high frequency, high wave number fluctuations
occurring in the near-surface internal waves of the central Gulf of Mexico. As
illustrated in Figure 1, the experiment will use three types of instrument plat-
forms: A ship for taking environmental data; a NOAA data buoy for taking meteo-
rological and surface wave data; and a single-point subsurface mooring for takin
ocean current and mooring dynamics data. The single-point subsurface mooring,
which was selected over other classes of moorings because of cost, reliability, a
deployment considerations, is the primary instrument platform. It will contain 2
current meters — 17 located in the near-surface (upper 300 m of water) and the re-
mainder spread over a significant portion of the water depth. It will be
anchored near the data buoy in about 3300 m of water, and will take data for
approximately seven weeks.

During the initial planning phase of the experiment, a preliminary design of
the subsurface mooring was proposed. This design is shown schematically in Fig-
ure 2, and is intended to satisfy the need for a reasonably rigid measurement pla
form. As a next step in the design process, the performance of the proposed desi
was predicted by using several computer programs developed for static and dynamic
mooring analyses. This is an important step since it allows the designer a com-
parison of the probable performance with that which is desired. Also, such analy
ses are useful in optimizing the design from the possibilities available.

This paper covers the problems analyzed during the initial planning phase of
the experiment. Presentations include prediction of the mooring response to forc
ing caused by ocean currents, waves, and system deployment. Because the forcing
considered can be classified as either time-independent or time-dependent, the
paper is divided appropriately into two broad analytical categories. The first
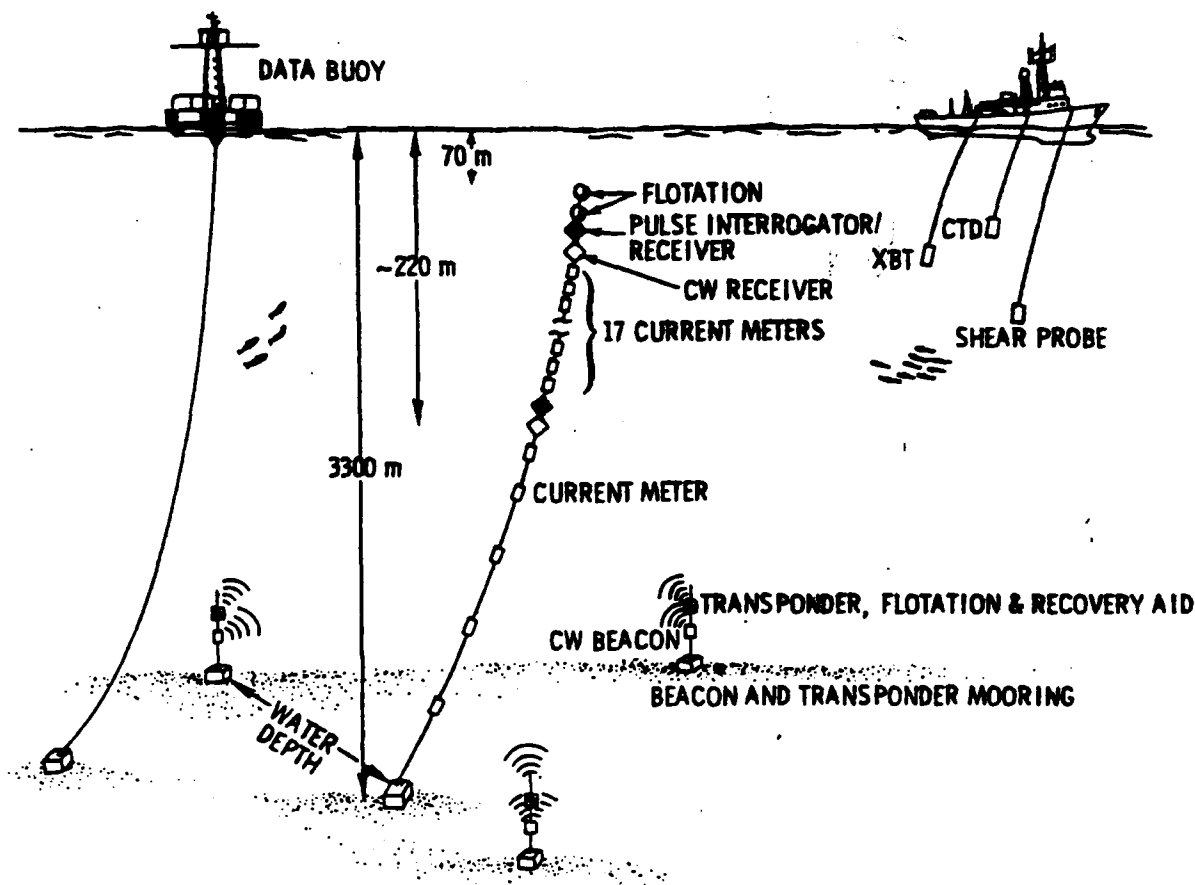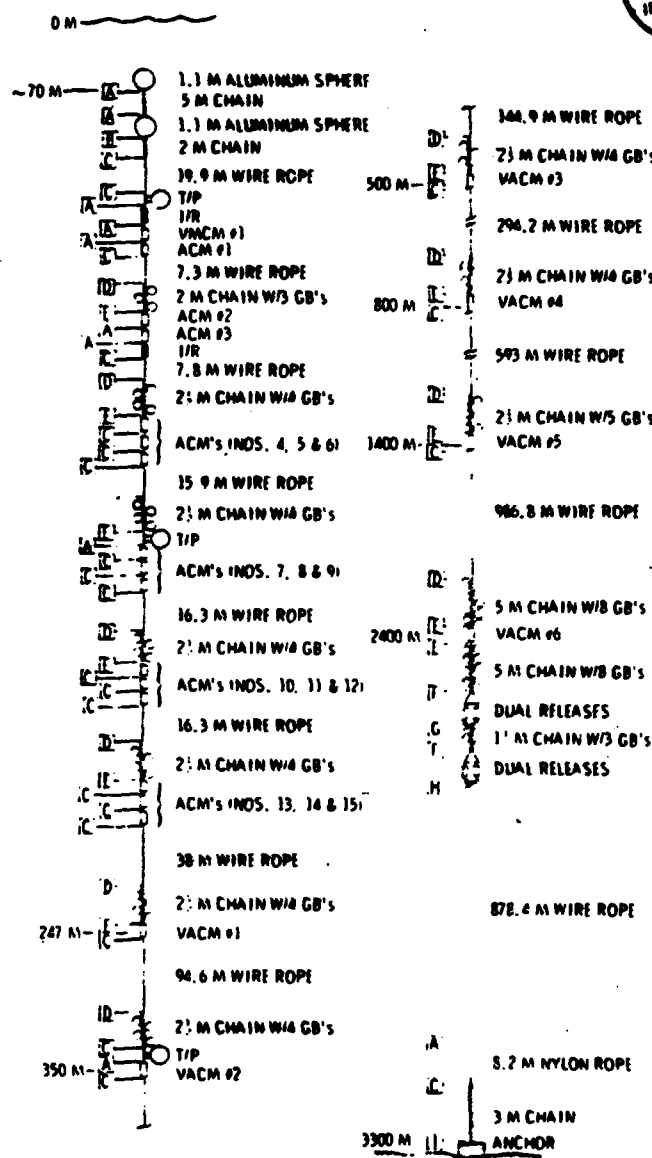
Figure 1. Schematic illustration of the experiment. As presently
planned, the subsurface mooring shown in the center will be deployed
in mid-December 1979. To evaluate and possibly correct the motion-
contaminated current meter records, it will contain: acoustic re-
ceivers for motion measurement, and instruments for measuring such
parameters as depth, temperature, tension, acceleration and incli-
nation.

category considers the static analyses, and the second the dynamic analyses. The
computer programs used to solve these analysis problems are briefly described at
the beginning of each section. These computer programs are based on state-of-the-
art mathematical models of cable moored systems[1] and, in addition to environmental
forcing, require certain physical and hydrodynamic data for the mooring components
as inputs. Reliable data for the components of the subject mooring were garnered
from manufacturers data and from Reference 2.

Static Analyses

The computer programs used to solve the problems in this section are thorough-
ly described in References 3 and 4. They can model currents that vary in both
magnitude and direction with depth. In solving the problems below, the following
important features were considered: mooring line elasticity, normal and tangential
hydrodynamic loading on mooring lines, forces due to gravity, in-line lengths of
instruments and tackle, and drag forces on instruments.

2

0 M

~70 M

1.1 M ALUMINUM SPHERE
5 M CHAIN
1.1 M ALUMINUM SPHERE
2 M CHAIN
39.9 M WIRE ROPE
T/P
I/R
VMCM #1
ACM #1
7.3 M WIRE ROPE
2 M CHAIN W/3 GB's
ACM #2
ACM #3
I/R
7.8 M WIRE ROPE
2½ M CHAIN W/4 GB's

ACM's (NOS. 4, 5 & 6)

15.9 M WIRE ROPE
2½ M CHAIN W/4 GB's
T/P

ACM's (NOS. 7, 8 & 9)

16.3 M WIRE ROPE
2½ M CHAIN W/4 GB's

ACM's (NOS. 10, 11 & 12)

16.3 M WIRE ROPE
2½ M CHAIN W/4 GB's

ACM's (NOS. 13, 14 & 15)

38 M WIRE ROPE

2½ M CHAIN W/4 GB's

VACM #1

94.6 M WIRE ROPE

2½ M CHAIN W/4 GB's

247 M

T/P
VACM #2

350 M

500 M

144.9 M WIRE ROPE
2½ M CHAIN W/4 GB's
VACM #3

294.2 M WIRE ROPE

2½ M CHAIN W/4 GB's
VACM #4

800 M

593 M WIRE ROPE

2½ M CHAIN W/5 GB's
VACM #5

1400 M

966.8 M WIRE ROPE

2400 M

5 M CHAIN W/8 GB's
VACM #6

5 M CHAIN W/8 GB's

DUAL RELEASES
1 M CHAIN W/3 GB's
DUAL RELEASES

878.4 M WIRE ROPE

8.2 M NYLON ROPE

3 M CHAIN
3300 M   ANCHOR

NOTES:

1. ALL WIRE ROPE IS 3/16" DIAMETER, AND IS 3 x 19 TORQUE BALANCED CONSTRUCTION.

2. ALL CHAIN IS 1/2" GALVANIZED STEEL.

3. THE NYLON ROPE (NEAR ANCHOR) IS 1" DIAMETER, AND IS A BRAIDED CONSTRUCTION.

NOTATION:

T/P	•	TEMPERATURE AND PRESSURE RECORDER
I/R	•	INTERROGATOR AND RECEIVER
VMCM	•	VECTOR MEASURING CURRENT METER
ACM	•	ACOUSTIC CURRENT METER
VACM	•	VECTOR AVERAGING CURRENT METER
GB	•	GLASS BALL (16" DIAMETER)
A	•	1/2" SHACKLE
B	•	1/2" SHACKLE, 1/2" MASTER LINK AND 1/2" SHACKLE
C	•	1/2" SHACKLE, 1/2" SWIVEL AND 1/2" SHACKLE
D	•	1/2" SHACKLE AND 3/8" SHACKLE
E	•	3/8" SHACKLE, 1/2" SHACKLE, 1/2" SWIVEL AND 1/2" SHACKLE
F	•	3/8" SHACKLE
G	•	E AND F
H	•	1/2" MASTER LINK AND C
I	•	1/2" MASTER LINK AND 3/8" SHACKLE

Figure 2. Preliminary design of the single-point subsurface mooring. The instruments denoted above by T/P and I/R are a tentative choice.

Design Check

The proposed design, as originally synthesized, was based on simple static, hand-calculations to size the mooring lines and tackle for adequate strength. These calculations did not include such important considerations as cable stretch, in-line lengths of instruments and tackle, back-up recovery tensions[5], and descent tensions resulting from system deployment. Hence, the problem here was to analyze the original design with the static computer programs mentioned previously, and to modify it, as necessary, to meet the following performance criteria in the absence of any currents:

    a. A minimum system safety factor of 2.5 while moored and 2.0 during deployment.

b. A minimum back-up recovery tension of 440 N at any point above th
upper set of acoustic releases. In the event that the mooring should break at
point above the acoustic releases, this will provide sufficient buoyancy to re
the mooring parts remaining.

c. The depths desired for the current meters and top buoy.

To meet these performance criteria, the original design was modified by sh
ening the lengths of rope and by adding five more glass balls above the upper
of acoustic releases. Figure 2 presents the proposed design with these modifi
tions. It also shows the unstressed lengths of cable required to achieve the
ponent depths desired. The minimum system safety factors found in the analysi
were 2.7 while moored and 2.1 during deployment. This latter safety factor is
based on a steel, dead-weight anchor weighing 13.34 kN in water. Also, it was
found that the system has a descent rate of 90 cm/s, and that the minimum back
recovery tension is 534 N.

Response to Steady-State Current Profiles

Two planar current profiles, which will be referred to in subsequent disc
sions as the typical and maximum expected profiles, were used in this problem.
Each of these has constant currents that act in a horizontal direction and var
with depth. The typical profile (whose current varies exponentially and cosin
soidally with depth) is shown in Figure 3, and the maximum expected profile (wh
current varies exponentially with depth) in Figure 4. Using ocean current dat
garnered from physical oceanographers, both profiles were constructed to provi
worst case conditions at the site of the experiment.

The configuration of the mooring when subjected to the typical current pr
file is shown in Figure 3. Although inclined, it is quite straight with tilt
angles (defined with respect to the vertical) varying from about 7 to 10 degre
This indicates that mooring will be reasonably rigid under normal current con-
ditions. When subjected to the stronger maximum expected current profile, the
mooring configuration changes to the one shown in Figure 4. In particular, the
excursions of the top buoy change from 510 m to 640 m horizontally and from 42
to 65 m vertically. Figure 4 shows that the top two buoys remain well above th
maximum allowable depth limit.

In each of the above mooring configurations, the tension distribution was
found to be about the same as that of the no current mooring configuration. He
the system safety factor remains essentially unchanged for the current profiles
The largest horizontal component of tension at the anchor was found to be 2560
and occurs (as expected) when the mooring is subjected to the maximum expected
current profile. Thus, to keep the mooring on station for the duration of the
experiment, it is necessary to use an anchor that can resist this horizontal pu
It can be shown that a dead-weight anchor weighing 16 kN in water has sufficien
holding power[5]. Another approach, however, is to use a dead-weight anchor weig
ing 13.34 kN in water in conjunction with a Danforth anchor weighing about 150
Because of its lighter weight, this latter approach is recommended.

To examine the effect of increased buoyancy and cable drag on mooring re-
sponse, two cases with the typical current profile as forcing were considered.
the first case, the top buoy on the mooring was replaced by one having enough
buoyancy to produce a system safety factor of 2, which is a lower limit. Relat
to the response of the unmodified mooring, this change resulted in an 11% decre
in horizontal excursions and about a 25% decrease in system safety factor. On
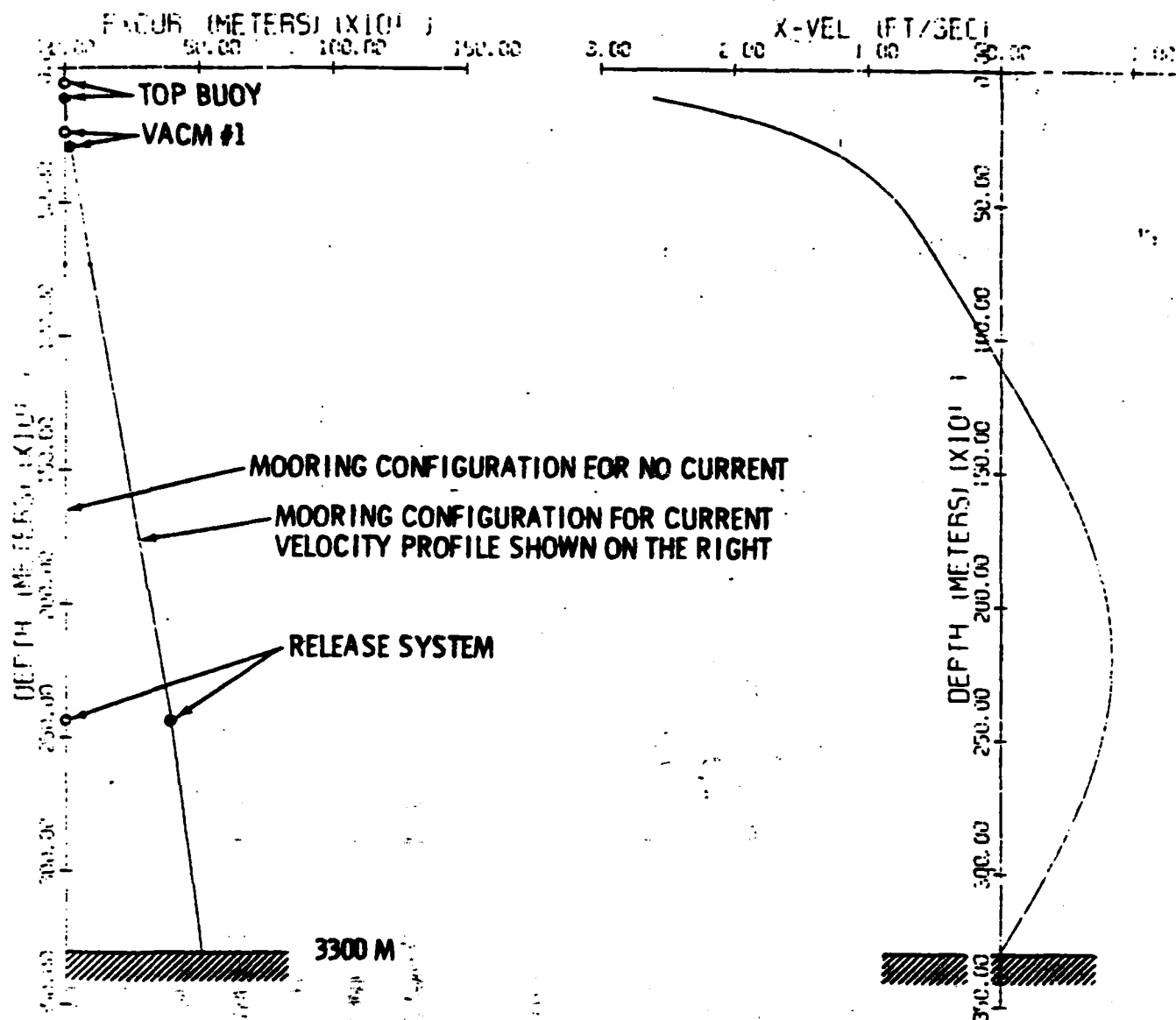
Figure 3. The mooring configuration (left) when subjected to the typical current profile (right). Note that the circles shown correspond to the no current configuration.
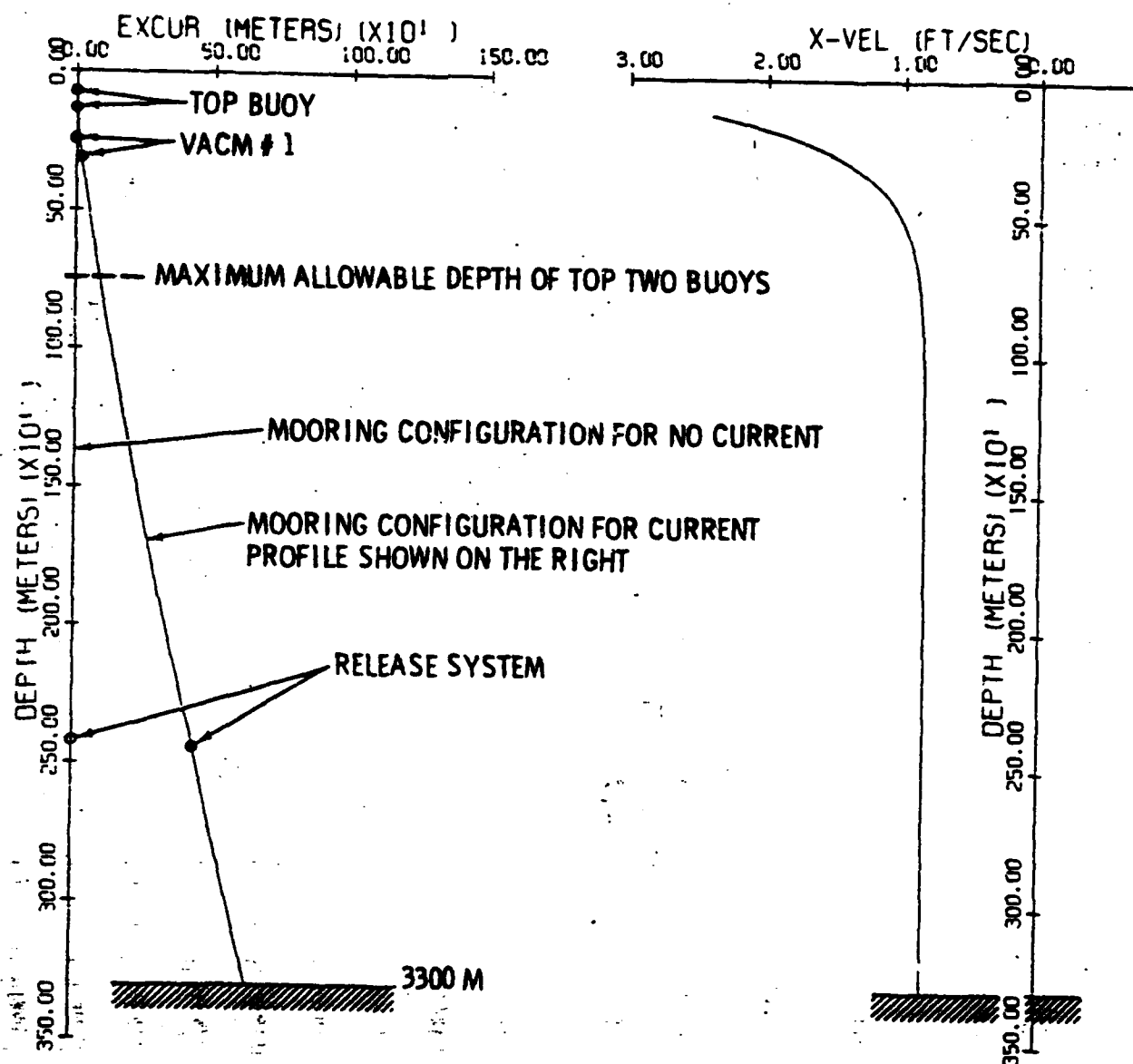
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Figure 4. The mooring configuration (left) when subjected to the maximum expected current profile (right). Note that the circles shown correspond to the no current configuration.

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weighing these results, it appears that the addition of buoyancy is not an attra[ctive] design consideration. For the second case, normal drag coefficients for th[e] mooring ropes were increased from their nominal values of 1.4 to 1.8. This chan[ge] intended to account for some degree of cable strumming, resulted in a slight in- crease in horizontal excursions (about 3%) and essentially no change in the moor- ing tensions.

Response to a Uniformly Rotating Current Profile

Because ocean currents are not steady but continuously change direction and speed, a mooring will continuously seek a new equilibrium configuration. This co[n]- tinual readjustment is termed mooring motion, and its magnitude can determine th[e] usefulness of the mooring for current measurements. For slowly changing current[s] it is reasonable to assume that the mooring displacements will keep up with thes[e] currents. Hence, at any instant in time, the mooring will remain in static equi- librium with the current.

In the Gulf of Mexico, inertial and tidal currents change slowly; and, becaus[e] of their large vertical scales, are believed to be the primary cause of low fre- quency mooring motion. To examine current meter errors, these currents were modeled in this problem by the typical current profile rotating at a constant rat[e] of 2π radians in 12 h. The case of a uniformly rotating current profile is in- structive since the mooring motion is most pronounced under these circumstances. Also, it simplifies the computation of current meter errors because the mooring will respond with pure rotational motion.

The horizontal motion of the mooring's current meters, found by applying a static analysis to the uniformly rotating current profile, is plotted in Figure 5[.] Since the motion is circular, the absolute speed of any current meter, V_m, is given by

$$V_m = \omega R$$

where ω is the constant rate of rotation and R is the horizontal excursion of the current meter. And, since V_m is perpendicular to the current, V, the relative speed measured by the current meter, V_R, is found as

$$V_R = (V^2 + V_m^2)^{\frac{1}{2}} = (V^2 + (\omega R)^2)^{\frac{1}{2}}$$

Table 1 presents some errors for selected current meters on the mooring. These errors were calculated from the following formulas:

$$E_m = (V_R - V)/V$$

and

$$E_p = \tan^{-1}(V_m/V)$$

where E_m is the speed error and E_p is the phase error. As can be seen, the speed of the uppermost meter through the water is 7.4 cm/s. Although the lower meters have less speed, some of them have significantly larger errors compared to the up- per meters. This occurs, as shown in Table 1, when the meter speed approaches tha[t] of the current.

7

510 M RADIUS

DISP (METERS) (X10¹)

60.00

40.00

20.00

-0.00

-20.00

-40.00

-60.00

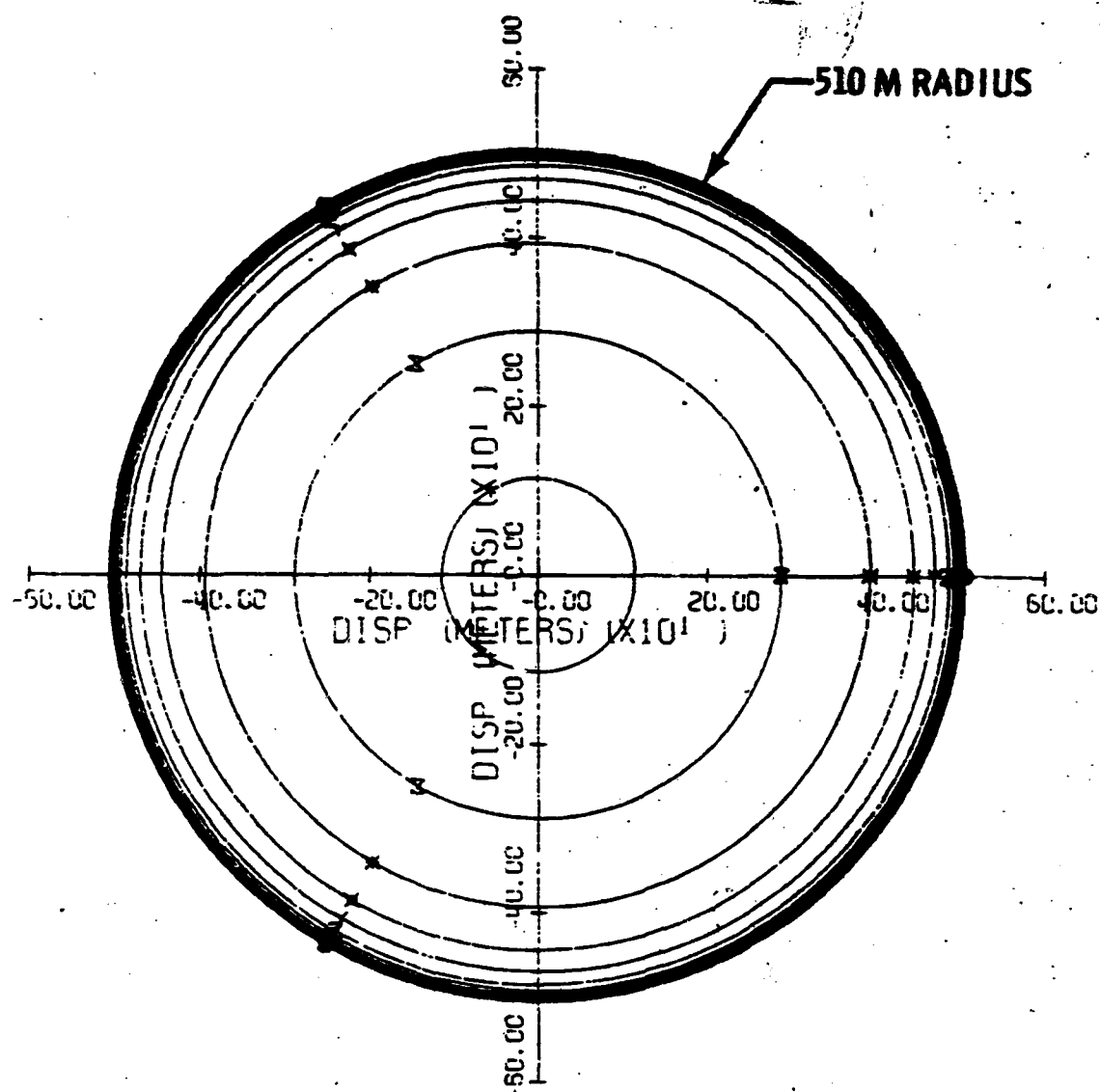-60.00 -40.00 -20.00 -0.00 20.00 40.00 60.00

DISP (METERS) (X10¹)

Figure 5. The circles shown represent the horizontal
motion of the current meters when the mooring is sub-
jected to the uniformly rotating current profile. The
outer circles are for the uppermost current meters,
and the origin of the coordinate system shown corre-
sponds to the anchor.

TABLE 1

Mooring Response to Uniformly Rotating Current Profile

Component	Depth (m)	Horizontal excursion (m)	Tilt (degrees)	V (cm/s)	V_m (cm/s)	E_m (%)	E_p (degrees)
ACM #1	146	510	4	67.7	7.4	0.6	6.3
ACM #15	244	498	8	46.7	7.3	1.2	8.8
VACM #1	283	491	9	41.2	7.2	1.5	9.9
VACM #2	385	475	9	30.7	6.9	2.5	12.7
VACM #3	534	450	10	21.7	6.5	4.4	16.7
VACM #4	830	398	10	10.0	5.8	15.7	30.2
VACM #5	1421	292	10	-11.4	4.2	6.7	20.4
VACM #6	2405	118	10	-24.6	1.7	0.2	4.0

Dynamic Analyses

Two methods were used to solve the dynamic problems presented in this section. In one method, the mooring line was modeled as a continuous elastic material. In the other method, the mooring was represented by a lumped parameter model consisting (as shown in Figure 6) of seven masses joined by elastic springs that are capable of stretching only. The former method was used to solve the first problem given below, and the latter method the two remaining problems.

All three problems were solved in the time-domain by the computer programs described in References 6 and 7. In solving these problems, the following important features were considered: mooring line elasticity, nonlinear hydrodynamic drag forces, and inertia forces with added mass included.

Response to a Time-Varying Current Profile

In this problem, the mooring excitation is provided by ocean currents that change in magnitude and direction with depth and time. These currents, obtained from physical oceanographers who derived them from a Garrett-Munk spectrum, are believed to be the most expected currents in the area of the experiment.

Figure 7 presents the motion response of the top buoy. It can be seen that the motion is dominated by a semidiurnal oscillation, and has maximum horizontal excursions of 100 m and maximum vertical excursions of 2 m. This motion was observed throughout the mooring, but with excursions reducing from a maximum at
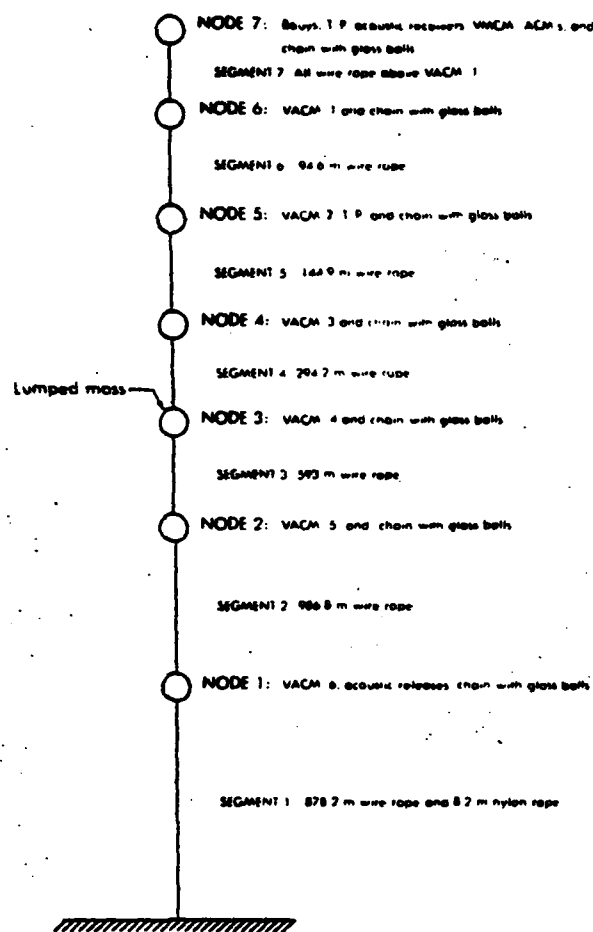
NODE 7: Buoy, 1.9 acoustic receiver, VACM, ACM's and
chain with glass balls

SEGMENT 7 All wire rope above VACM 1

NODE 6: VACM 1 and chain with glass balls

SEGMENT 6 940 m wire rope

NODE 5: VACM 2, 1.9 and chain with glass balls

SEGMENT 5 144.9 m wire rope

NODE 4: VACM 3 and chain with glass balls

SEGMENT 4 294.2 m wire rope

Lumped mass —

NODE 3: VACM 4 and chain with glass balls

SEGMENT 3 393 m wire rope

NODE 2: VACM 5 and chain with glass balls

SEGMENT 2 986.8 m wire rope

NODE 1: VACM 6, acoustic releases, chain with glass balls

SEGMENT 1 878.2 m wire rope and 8.2 m nylon rope

Figure 6. Lumped parameter model
the subsurface mooring shown in Fig

·the top buoy to zero at the anchor. In particular, excursions were reduced
slightly down to the fifth VACM and by about 70% at the sixth VACM (see Figure
As shown on the left of Figure 7, the horizontal motion is not circular and, ov
the two successive cycles shown, has a zero mean displacement.

Response to Surface Gravity Waves

Three cases were considered to examine the effect of sea state on mooring
response. The mathematical model used to simulate sea state is a simple harmo
wave whose direction of propagation is constant with time and whose amplitude
decreases with depth in the classic fashion of surface gravity waves. To prov
a worst case condition, no case included ocean currents which, if present, wou
mitigate the effect of waves on the mooring. Each case, described by sea sta
below, has the following physical characteristics:

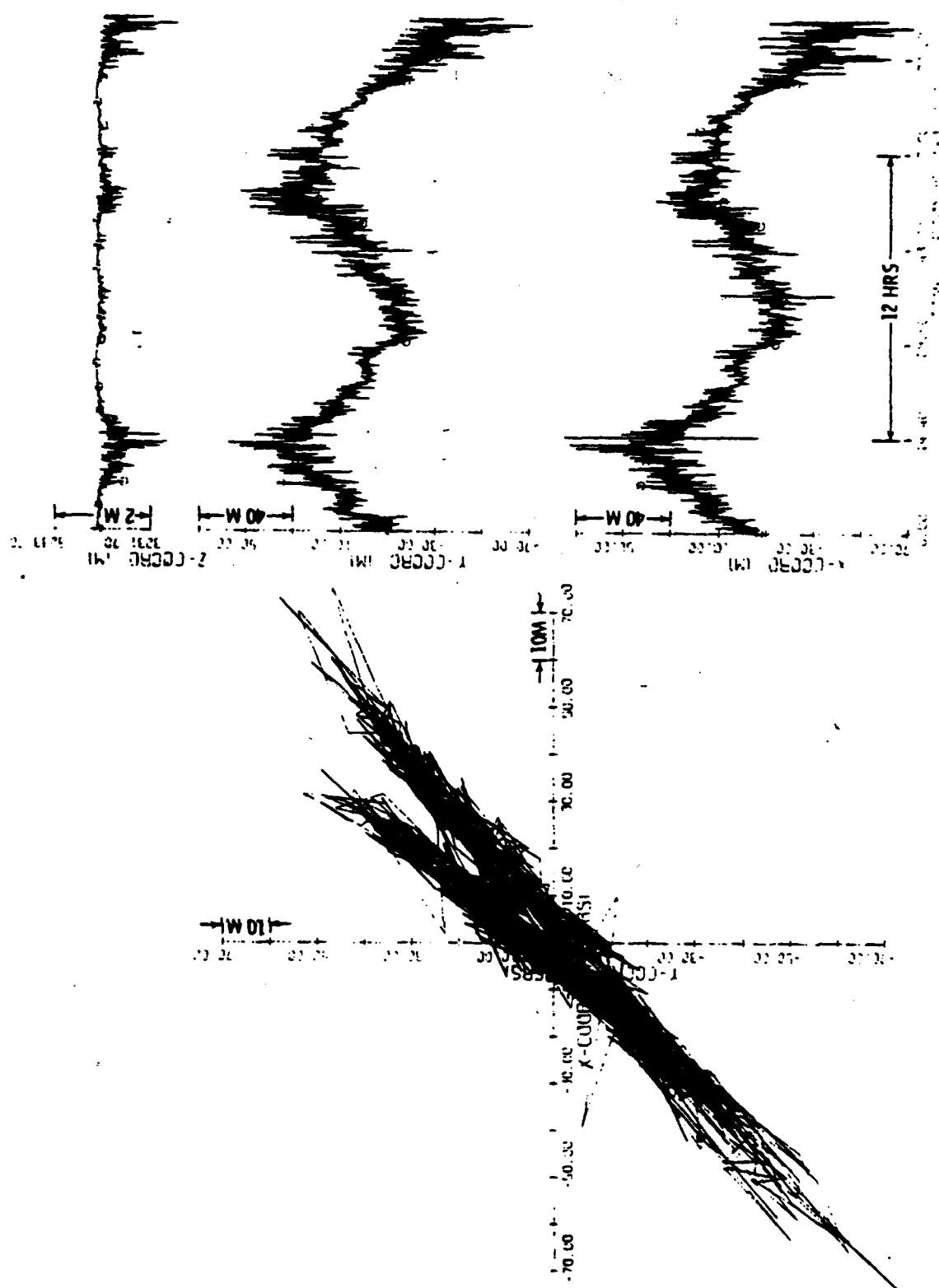| Case	Wave Period (Seconds)	Surface Wave Amplitude (Meters)	Percent Attenuatio at 70 meter depth
I. Sea State 4	7.5	1.0	0.6
II. Sea State 6	10.0	2.0	6.0
III. Sea State 7	15.0	5.6	29.0

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Figure 7. Motion response of the top buoy to ocean currents that change in magnitude and direction with depth and time: A time series of vertical (z-coordinate) and horizontal motion is shown on the right, and a top view of horizontal motions on the left.

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where the wave period is the period of maximum wave energy, and the surface ampl
tude is one-half the significant wave height.

The third case, corresponding to sea state 7, has a wave period correspond
to a natural frequency of the system, and was therefore selected to provide a
worst case condition. Natural frequencies of the system were determined by
analyzing the undamped, longitudinal vibration response of the mooring model.
first three of these, found by this eigenvalue analysis, have periods of 15.0,
and 2.1 seconds. For all practical purposes, surface gravity waves with periods
of 3.9 seconds, or less, are completely attenuated at a 70 meter depth. Conse-
quently, such waves were not considered.

Figure 8 presents the motion versus time response of two locations on the
mooring to the 15.0 s period wave, Case III. Results for the upper portion of
mooring, where 16 current meters are positioned, are shown on the left and resul
for a lower portion on the right. As shown, the upper portion of mooring fluc-
tuates 1.6 m horizontally and about 1.8 m vertically. Under the more expected s
conditions given by the 7.5 s and 10.0 s period waves, it was found that the ver
tical fluctuations of the upper portion of mooring are 1 and 13%, respectively,
of that of the 15 s period wave. Also, it is seen that the maximum tension occu
in the lower portion of the mooring where fluctuations are 1330 N. More impor-
tantly, these dynamic tensions should not break the mooring line by over stressi
it or by kinking it.

Transient Response During Deployment

The mooring will be deployed by the anchor-last technique. In this techniq
the floats at the top of the mooring are the first components to be launched.
These are then followed by the remaining mooring components up to the anchor.
Finally, the anchor is dropped when on location. This problem considers the moo
ing response to the free-falling anchor's impact with the ocean floor. It negle
the effects of ocean currents and waves. And, it assumes that the mooring is
vertical, and is falling at its terminal velocity just before impact. It furthe
assumes that the anchor does not move after impact.

The results of this one-dimensional analysis are presented in Figure 9 wher
longitudinal motion and tension are plotted versus time for selected points on t
mooring. They are shown converging to their static values after about 1-1/2
minutes, without much overshoot. More importantly, the tensions shown remain we
above any slack condition, indicating that kinking will not occur during this
phase of deployment.

Summary

The response of the proposed mooring design to excitation sources related t
its planned operating environment and deployment has been analyzed both statical
and dynamically. Using computer programs developed for such purposes, tensions,
in and motions of the subject mooring were predicted to evaluate and, if necessa
to optimize the design. The static analysis type-problems have concerned the
response of the mooring to steady-state currents, which are intended to represen
typical and extreme conditions for the operating area. Motions caused by tidal
and inertial currents, the primary cause of low frequency mooring motion, were
computed using a uniformly rotating current profile. These motions were then us
to estimate errors in the measured currents, assuming ideal current meters. Und
these slowly changing currents, it was found that the errors in the uppermost
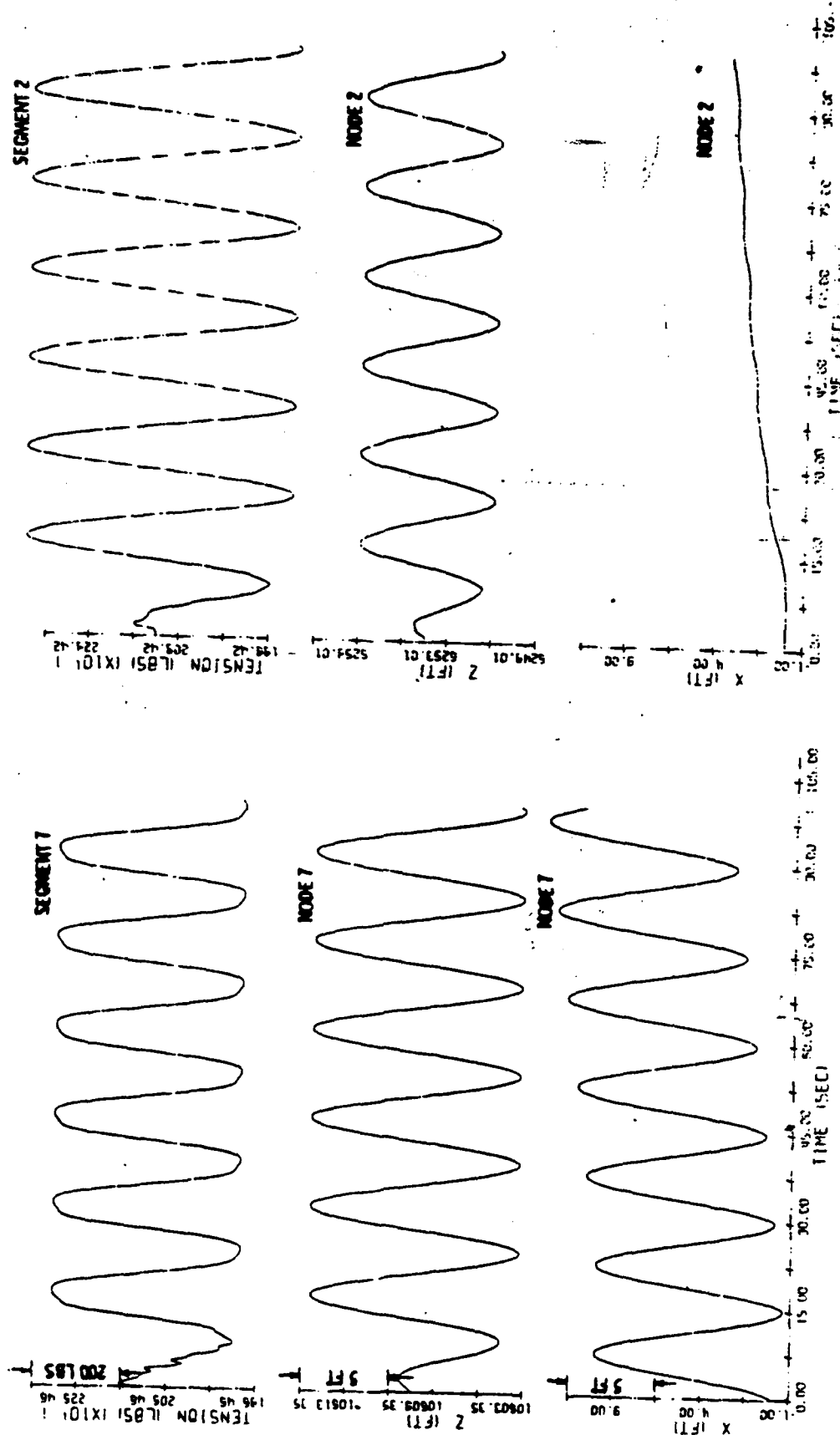current meters are considerably less than those found in most of the lower meter

Figure 8. Response of the mooring to a surface gravity wave having a period of 15 seconds and a surface wave amplitude of 5.6 m. Refer to Figure 6 for the correspondence of mooring components to the segments and nodes shown. Note that z is the vertical coordinate measured relative to the ocean floor, and that the wave is propagating in the positive x-direction.
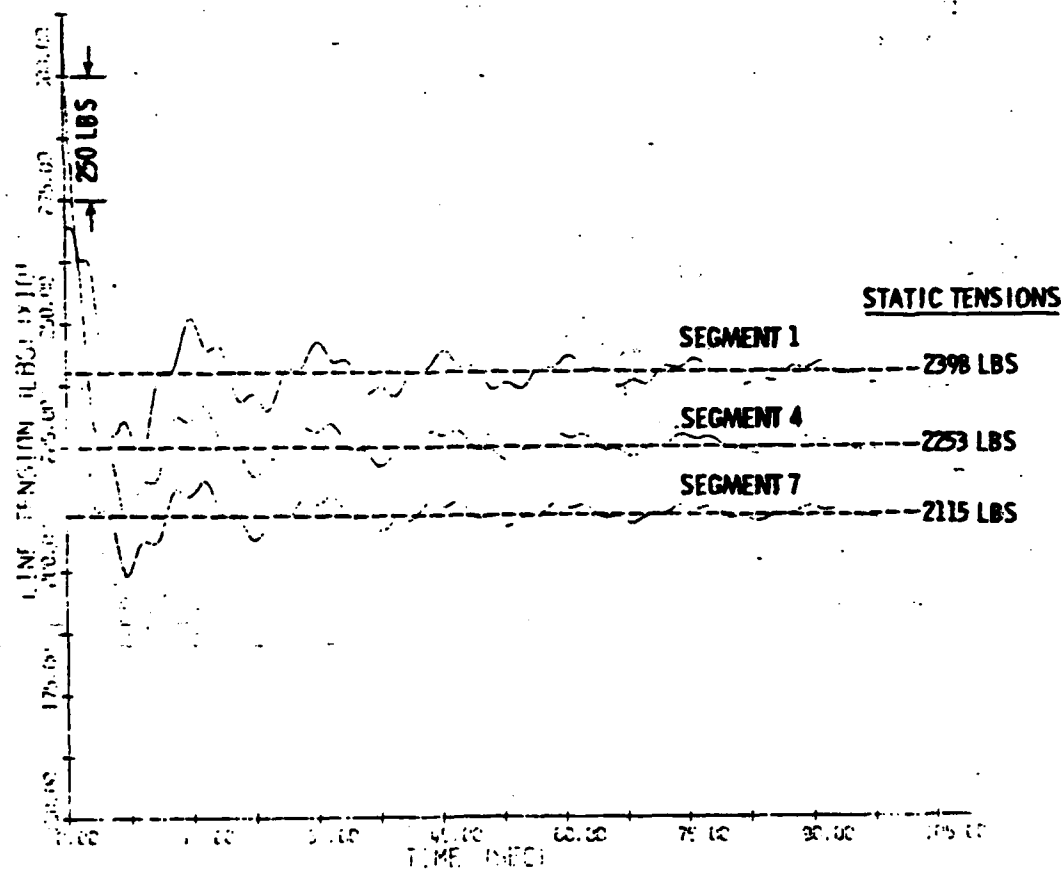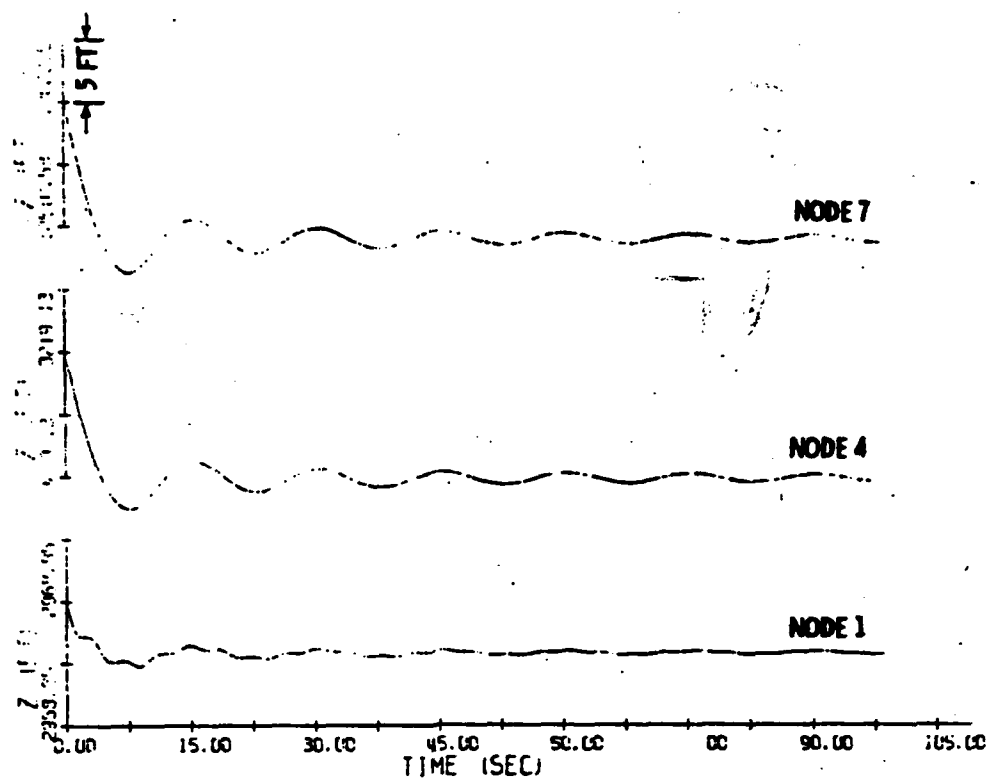
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Figure 9. Response of the mooring to the free-falling anchor's impact with the ocean floor. See Figure 6 for the definition of the segments and nodes shown.

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Also, at any instant in time, it was found that the mooring, although inclined, was quite straight with tilt angles varying from 7 to 10 degrees.

Using this same current profile, analyses were made to determine the effect of increased buoyancy and cable drag on mooring performance. It is concluded that the addition of buoyancy is not an attractive design consideration, and that increased cable drag caused by cable strumming only slightly effects mooring performance. Based on the analyses using the extreme steady-state currents, the following major recommendations concerning mooring components are made: Add five more glass balls above the acoustic releases for back-up recovery capability; and, use a dead-weight anchor (weighing about 13.3 kN in water) in conjunction with a Danforth anchor to keep the mooring on station for the duration of the experiment.

Three dynamic analyses were made to determine separately the effect of time-varying currents, ocean waves, and deployment on the mooring's performance. In regard to these analyses, it is concluded that under normal environmental conditions the mooring will be reasonably rigid and uneffected by ocean waves. Moreover, with high probability it should survive these and the other extreme conditions assumed.

References

1. Albertsen, N.D., "A Survey of Techniques for the Analysis and Design of Submerged mooring Systems," Civil Engineering Laboratory, Port Hueneme, CA, Technical Report R815, August 1974.

2. Pattison, J.H., et al., "Handbook on Hydrodynamic Characteristics of Moored Array Components," David W. Taylor Naval Ship Research and Development Center, Bethesda, MD, Report SPD-745-01, March 1977.

3. Chhabra, N.K., "Mooring Mechanics-A Comprehensive Computer Study," Volume I, C.S. Draper Laboratory, Inc., Cambridge, MA, Report R-775, November 1973.

4. Skop, R.A. and J. Mark, "A Fortran IV Program for Computing the Static Deflections of Structural Cable Arrays," Naval Research Laboratory, Washington, D.C., NRL Report 7640, August 1973.

5. Berteaux, H.O., Buoy Engineering, John Wiley & Sons, Inc., New York, 1976.

6. Chhabra, N.K., "Mooring Mechanics-A Comprehensive Computer Study," Volume II, C.S. Draper Laboratory, Inc., Cambridge, MA, Report R-1066, December 1976.

7. Chhabra, N.K., "Dynamic Motions of a Subsurface Mooring System at Anchor Impact After Its Free Fall to the Ocean Floor," C.S. Draper Laboratory, Inc., Cambridge, MA, Report R-1079, April 1977.

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